

Evidence for VHE emission from SNR G22.7-0.2 region with H.E.S.S.

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Observations of the supernova remnant G22.7-0.2 in the field of view of W41 with the H.E.S.S. telescope array have resulted in evidence for a very high energy (VHE) gamma-ray emission from the direction of the object. The emission region is spatially coincident with molecular clouds visible in ^{13}CO data, suggesting a hadronic origin of the TeV emission, although other scenarios brought by X-ray observations with the XMM-Newton satellite are also discussed. The latest results obtained on this SNR with H.E.S.S. and associated multi-wavelength information are presented here.

I. INTRODUCTION

The supernova remnant (SNR) G22.7-0.2 shows a non-thermal ring in radio [1] within a complex region and partially overlaps the remnant W41. G22.7-0.2 has an intrinsic diameter of 26' in radio and neither its distance nor its age have been estimated. However, Spitzer observations [2] show enhanced infrared emission between G22.7-0.2 and W41, which might be interpreted as an interaction between the two remnants. An interstellar cloud surrounded and shocked by both remnants seems likely to produce the observed IR emission. In such an assumption, the distance of G22.7-0.2 should be close to the estimated distance of W41 of 4.2 kpc.

Observations carried out with the H.E.S.S. telescope array have led to an indication of a VHE gamma-ray excess in positional coincidence with a fraction of SNR G22.7-0.2 radio shell. The features of this VHE emission are described in the second section.

Non-thermal emission is found at the gamma-ray excess position by the Effelsberg telescope at 11 cm [3] and 21 cm [4] wavelengths. Additional multi-wavelength counterparts are found at this position,

in particular in X-rays and in radio at the ^{13}CO ($J=1\rightarrow 0$) transition line energy. More details on these counterparts are given in the third section of this proceeding. The different considered scenarios that could explain the gamma-ray emission are discussed in the last section.

II. H.E.S.S. OBSERVATIONS

Situated near the galactic plane in a field of view rich in gamma-ray sources, evidence for a new VHE gamma-ray source was found thanks to observations dedicated to study the neighbouring sources, such as W41 which is bright in VHE gamma-rays as well [5]. To investigate such excess a detailed analysis of the region is performed. A standard run selection procedure is used to remove bad quality observations. This results in a data set comprising 50 hours live time of observations taken from 2004 to 2010. Then, Hillas analysis with standard Hillas-based cuts [6] including a minimum charge of 80 photo-electrons in the shower images is applied to the data. The background is estimated with the ring-background model, as described

in [6]. The image shows evidence at a significance level of 5.8σ pre-trials of a new compact VHE source dubbed HESS J1832-093. The corresponding excess map of this field of view is shown in Fig. 1.

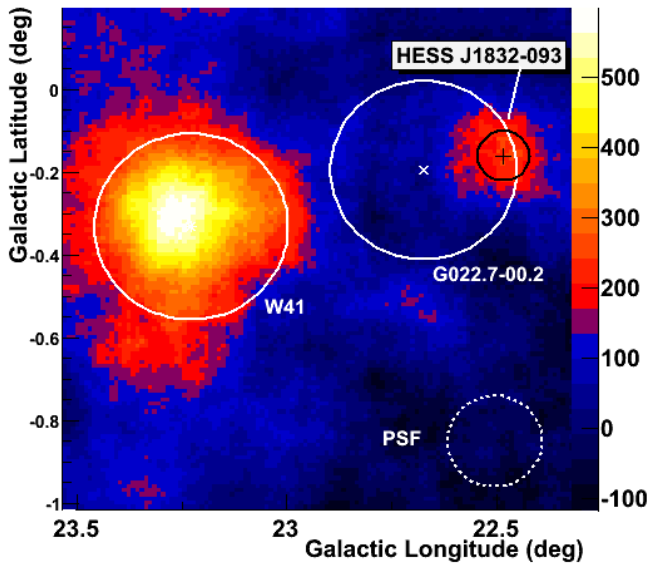


FIG. 1: H.E.S.S. correlated excess map to the r_{68} value of 0.11° at this position (represented by the dashed circle). The gamma emission from W41 is seen on the left of the image and the hot spot HESS J1832-093 on the right. Its best fitted position with corresponding errors is represented by the black cross and its intrinsic size by a black circle. The apparent sizes of the SNR observed in radio are symbolized by white circles.

The average angular resolution r_{68} , defined as 68% containment of the point spread function (PSF), is 0.11° for these standard cuts at the source position and for these observations. A two-dimensional Gaussian function is used to determine the position and size of the TeV emission. The best fitted position is $l = 22.48^\circ \pm 0.02^\circ_{\text{stat}}$, $b = -0.16^\circ \pm 0.02^\circ_{\text{stat}}$ in galactic coordinates, with a systematical pointing error of 0.01° . The source appears slightly extended with an intrinsic size of $0.06^\circ \pm 0.02^\circ$ estimated by using the 2D Gaussian function adjusted on the excess map and taking into account the PSF value at this position.

To produce the energy spectrum, only high quality data are used. Therefore the run selection is restricted to observations runs with four triggering telescopes only and with a pointing position less than 2.1° away from the source center. This results in a data set of 36 hours live time. The background is estimated with the reflected background model [6], better suited for spectral studies. Since the source is slightly extended, the region used to estimate the flux has to be large enough to contain all the signal from HESS J1832-093 but not too big to avoid signal contamination from W41. We thus choose a circular region of 0.15° radius around the position of the source.

The obtained spectrum is well described by a power-law model and the integral flux above 1 TeV of $\Phi(E > 1 \text{ TeV}) = (1.7 \pm 0.9_{\text{stat}} \pm 0.3_{\text{syst}}) \times 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}$ corresponds roughly to 0.7% of the Crab nebula flux above the same energy.

III. MULTI-WAVELENGTH COUNTERPARTS

A. X-ray observations

Following the indication of the H.E.S.S. source, XMM-Newton was used to observe the gamma-ray emission region in March 2011. Only 7 ks of data out of 17 ks are usable for analysis due to proton flare contamination. The data were processed using the XMM-Newton Science Analysis System (v10.0) and the instrumental background (both for image and spectra) was derived from a compilation of blank sky observation [7] renormalized in the 10-12 keV energy band.

A point-like source with hard, highly absorbed spectrum is lying very close to the best fitted position of the TeV emission. The center of the X-ray source is indeed $30''$ away from the fitted position of the H.E.S.S. excess, but both positions are compatible within the statistical errors. No extended emission from non-thermal X-rays was found in these data. The unabsorbed flux between 2 and 10 keV of the point source is found to be $\Phi(2-10 \text{ keV}) = 6_{-5}^{+3} \times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1}$, with a spectral index of $\Gamma = 1.3_{-0.5}^{+0.6}$ and a column density of $N_H = 6.9_{-2.1}^{+2.8} \times 10^{22} \text{ cm}^{-2}$. The latter is three to six times larger than the total Galactic H I column density [8] averaged on a cone of 0.5° radius around the gamma-ray source position. The quite large derived column density indicates that the source is possibly distant and likely to lie behind dense molecular material (one of the clouds presented in the next section). The point-like source has spectral features which mimic a pulsar-like spectrum but no variability is found in the light curve of X-ray data. However, due to the weak statistics, no strong constraints could be derived.

B. ^{13}CO observations: association with molecular clouds

The Galactic Ring Survey (GRS) performed with the Boston University FCRAO telescopes [9] provides measurements of the ^{13}CO ($J=1 \rightarrow 0$) transition line covering the velocity range from -5 to 135 km s^{-1} in this region. The detection of this line is evidence for the presence of dense molecular clouds that are known to be cosmic-ray targets and hence gamma-ray emitters via neutral pion production and decay. A square

region of 0.2° side is defined around the source HESS J1832-093 to look for spatially coincident molecular clouds traced by the ^{13}CO transition line. Several molecular clouds are found in this region, as it can be seen in Fig. 2 showing the antenna temperature as a function of the measured radial velocity of the ^{13}CO transition line.

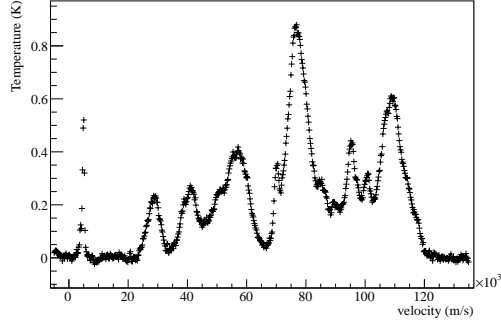


FIG. 2: Average ^{13}CO ($J=1\rightarrow 0$) transition line observed in the GRS [9] around the position of the TeV emission in a 0.2° side square region.

Each peak represents a molecular cloud, the mean velocity of a peak is related to the velocity of the considered cloud and its width characterizes the velocity dispersion due to the molecules agitation inside the cloud. The measured radial velocities can then be translated into distances using the Galactic rotation curve model provided by [10]. Given our position in the galaxy, two distances are therefore possible for each velocity. The molecular clouds that are most spatially coincident with the gamma-ray source are selected, corresponding to peaks (a) and (b) in Fig. 2. These clouds are shown in color in Fig. 3 with overlaid VHE gamma-ray significance contours. We use the associated antenna temperatures to estimate the cloud mass for each possible distance, as described in [11]. An equivalent radius R_{eq} is then determined from the apparent size of the clouds, with which we define a sphere to approximate the volume of each cloud, allowing us to calculate the cloud densities. The obtained parameters for both clouds shown in Fig. 3 are listed in Table I. **DISCUSSION**

The position of the gamma-ray emission lies on the edge of the remnant G22.7-0.2 and is spatially coincident with molecular clouds, suggesting different possible scenarios. First, cosmic rays that could be accelerated in the remnant might interact with a molecular cloud and produce neutral pions, their decay leading to the observed TeV emission. A second scenario involves electrons accelerated in the remnant with the production of VHE gamma-rays via Bremsstrahlung radiation in the molecular cloud.

To test the hadronic scenario, we use the parameters

Parameters	Close distance	Far distance
Cloud (a)	3.2 kpc	13.8 kpc
R_{eq}	7 pc	31 pc
Mass	$1.2 \times 10^3 M_\odot$	$2.3 \times 10^4 M_\odot$
Density	15 cm^{-3}	4 cm^{-3}
Parameters	Close distance	Far distance
Cloud (b)	4.8 kpc	10.5 kpc
R_{eq}	13 pc	28 pc
Mass	$2.7 \times 10^4 M_\odot$	$1.3 \times 10^5 M_\odot$
Density	64 cm^{-3}	30 cm^{-3}

TABLE I: Equivalent radius, mass and density of clouds (a) and (b) for the two possible distances [10].

derived for the clouds in Table I and the gamma-ray flux above 1 TeV obtained with the spectral study (see section II). The expected gamma-ray flux in such a scenario is [12]:

$$F_\gamma(E > E_0) \approx 9 \times 10^{-11} \theta \left(\frac{E_0}{1 \text{ TeV}} \right)^{-1.1} \left(\frac{E_{SN}}{10^{51} \text{ erg}} \right) \times \left(\frac{d}{1 \text{ kpc}} \right)^{-2} \left(\frac{n}{1 \text{ cm}^{-3}} \right) \text{ cm}^{-2} \text{ s}^{-1} \quad (1)$$

where θ is the fraction of the total kinetic energy released by the supernova (E_{SN}) going into accelerated cosmic rays energy, d denotes the distance to the object and n the density of the cloud. As we know the gamma-ray flux above 1 TeV and derived a density for a given distance, we can compute the θ fraction considering a supernova energy of 10^{51} erg. Since the gamma-ray excess is situated only on the edge of the remnant, we also included the solid angle of the clouds seen by the SNR. The θ fractions obtained are respectively 0.3% and 0.6% for clouds (a) and (b) for the closest distance, 27% and 6% for the furthest distances. Except for the far distance of cloud (a), the derived fractions are well below the 10% usually taken in the models. However, cloud (b) seems favoured in this scenario since the computed density and mass are higher. Thus, with more targets for the cosmic-rays, it is more likely to be the origin of the VHE gamma-ray emission. Moreover, the obtained distance of 4.8 kpc is quite close to the distance of W41 that is supposed to be in interaction with G22.7-0.2 as suggested in [2]. On the other hand, cloud (a) is more spatially coincident with the gamma-ray emission than cloud (b) (see Fig. 3).

As mentioned in section III A, a point source with pulsar-like spectrum shape has been found very close to the best fitted position of the H.E.S.S. emission. The high column density derived could imply a possibly distant source. The point source in X-rays is seen neither in IR [2], nor in radio at 21cm and 90cm wavelengths [1]. Although the proximity of the X-ray

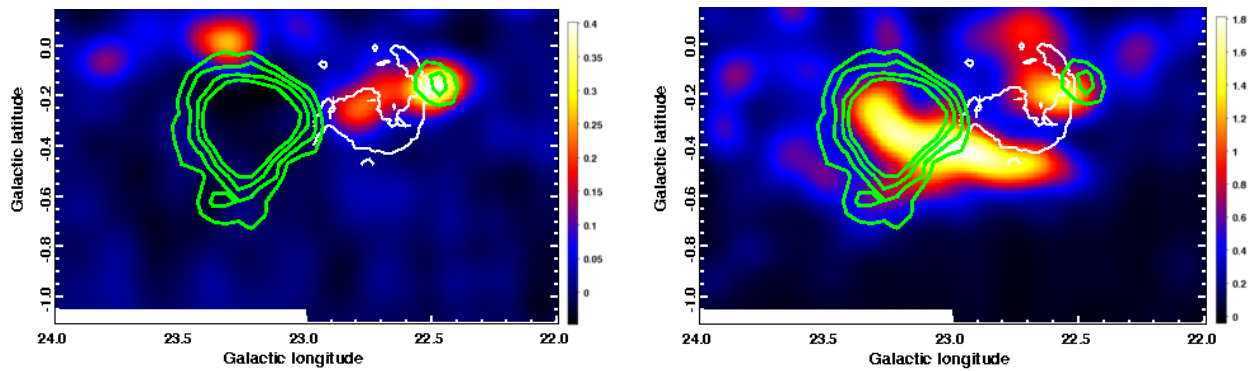


FIG. 3: ^{13}CO antenna temperature [9] in color at 28 km s^{-1} for cloud (a) (left) and 77 km s^{-1} for cloud (b) (right) smoothed with the average H.E.S.S. PSF for this data set. The gamma-ray significance contours from 4σ to 7σ are shown in thick green while the radio observation of SNR G22.7-0.2 [1] is overlaid in thin white contours.

source and the best fitted position of the TeV source is striking, the lack of X-ray pulsations does not support a scenario based on pulsar wind nebula (PWN). Besides, we did not find any PWN-like emission in the X-ray data that could come from a potential nebula associated with the point-source. However, this assumption cannot be ruled out since the flux from a distant PWN would be very weak and the very short observation time does not allow us to see such a faint emission. Furthermore, giving the high column density measured for the point-source, the emission coming from the hypothetical PWN could have been partially absorbed along the line of sight.

No Fermi source is found at the position of the H.E.S.S. excess, but the Fermi source 2FGL J1834.3-0848, potentially associated with the remnant W41, is situated less than 1° away from HESS J1832-093. The angular resolution of the Fermi LAT could thus prevent to distinguish between the two sources.

V. CONCLUSION

Observations in the field of view of the supernova remnant G22.7-0.2 with the H.E.S.S. telescope array have led to evidence for a TeV emission in positional coincidence with a fraction of the SNR radio shell. The source HESS J1832-093 reaches a significance level of 5.8σ applying standard Hillas-based cuts [6]. It appears slightly extended with an intrinsic size of $0.06^\circ \pm 0.02^\circ$. The source is quite faint since the integrated flux above 1 TeV is about 0.7% of the Crab nebula flux above the same energy.

The spatial coincidence with ^{13}CO enhancements measured through the GRS [9] suggests an interaction with a molecular cloud, thus implying hadrons or electrons accelerated in the SNR G22.7-0.2 that would produce gamma-rays in the considered cloud by neutral pions production or Bremsstrahlung radiation respectively. The latter scenario was not investigated

here. We have shown that the hadronic scenario is energetically achievable by computing the fraction of the supernova kinetic energy required to produce the observed gamma-ray flux using Eq. 1 [12].

On the other hand, recent observations in the X-ray band with the XMM-Newton satellite have brought another possible explanation for the observed TeV emission, even though the lack of information does not allow us to deeply investigate that scenario. The discovered point-like source presents a hard spectrum and lies within the best fitted position of the gamma-ray excess. This source has pulsar-like spectral features but no pulsations were found in the X-ray data. The large column density indicates that it should be quite distant, thus, considering the very short observation time, we don't expect to see any extended emission coming from a possible nebula associated to the X-ray source. More observations to determine the nature of the X-ray source are crucial to further investigate this possible scenario.

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